Southern Forest Outlook: Study Plan

Co-leads: John Coulston[1], Daniel McInnis[2], Stephanie Laseter[1]

Issue leads:

Fire- Scott Goodrick[1], Danny Lee[1], and Shardul Raval[2]

Markets- Jeff Prestemon[1]

Water-Jim Vose[1] and Peter Caldwell[1]

[1]USDA Forest Service Southern Research Station
[2]USDA Forest Service Southern Region

1 Objective

The objective of the Southern Forest Outlook is to inform forest sector decision makers and the interested public about observed trends, anticipated futures, and critical issues based on authoritative synthesis and interpretation of existing science, data, and projections.

2 Background

Globally, and within the United States, there is significant uncertainty surrounding climate and socioeconomic futures. This uncertainty cascades through all sectors including forestry. While there is substantial assessment work progressing at the global-scale (e.g. Intergovernmental Panel on Climate Change - IPCC) and national-scales (e.g. Renewable Resource Planning Act - RPA), there is a need to understand the potential impacts of different climate and socioeconomic futures at finer scales. This is particularly true in the Southern U.S. where recent changes in land use, forest disturbance, and forest product markets, as driven by climate and socioeconomic shifts, have led to increasing uncertainty about the future of the forestry sector (see for example, Parajuli et al. 2019, Suttles et al 2018, Coulston et al. 2015, Thomas et al. 2017, Prestemon et al. 2015**,** Martin et al. 2017). It is these uncertainties that motivates an authoritative synthesis and interpretation of existing science, data, and projections in order to more fully understand and plan for the range of potential futures in the Southern U.S.

The Southern U.S. has a long history of regional assessments to address uncertainties within the forestry community. Wheeler (1970) published 'The South's Third Forest' which evaluated trends and synthesized current peer reviewed literature to examine the future of timber supply given increasing demand and concerns of underinvestment in private forest land. The South's Third Forest report was followed by The South's Fourth Forest (USDA 1988) which focused on re-evaluating many of the same questions. However, the Fourth Forest research relied on using timber market models and policy analyses to examine alternatives for reversing underinvestment in nonindustrial private forests. By the late 1990's, growth in forest management and timber production largely anticipated by the Third and Fourth Forest reports, coupled with the emergence of satellite chip mills, raised concerns about the sustainability of forests in the South (Wear and Greis 2002a, 2002b). These concerns motivated the Southern Forest Resource Assessment (SFRA). The Southern Forest Futures Project (SFFP, Wear and Greis 2013) assessment is the most current volume in the Southern Forest Assessment Library. The SFFP was driven by increasing urbanization, land ownership dynamics, and markets and included integrated change scenarios based on population, economic factors, and climate change.

Analyses and results detailed in the Southern Forest Assessment library have influenced the forest sector. The South's Third Forest identified strategies to encourage planting and increase management on private forests; protect forests from insects, diseases, and fires; and build stronger institutions for forestry training, technology transfer, and research. Its forecasts of population-driven urbanization and expansion of tree planting and timber production have been realized in the South. The South's Fourth Forest anticipated the growth in timber production realized through 2000 and pointed suite of programs and policies to encourage reforestation, management, and forest protection. The SFRA led to improved Best Management Practices (BMP) monitoring, helped to expand the Forest Inventory and Analysis program, provided a wealth of information for the first State Forest Action Plans, and led to broader engagement across the forestry community. Findings from the SFFP helped set research priorities at the USDA Forest Service Southern Research Station, provided the motivation for a high priority regional working forest conservation initiative (Keeping Forests), and increased the emphasis on understanding socioecological systems related to water resources.

In 2019, U.S. Forest Service and Southern Group of State Foresters (SGSF) leadership recognized a need to update the Southern Forest Assessment Library with a new regional assessment which is being called the Southern Forest Outlook (SFO). Recent changes in land use, forest disturbances, forest management, and forest product markets have led to increasing uncertainty about the future of the sector. While much of the assessment library remains relevant, new data, research results, and projection models allow for new insights into critical issues facing the South.

The USDA Forest Service Southern Research Station and Southern Region, along with the SGSF, will lead the SFO with the objective to inform forest sector decision makers and the interested public about observed trends, anticipated futures, and critical issues based on authoritative synthesis and interpretation of existing science, data, and 50-year projections. The results are expected to provide insights on the range of outcomes and uncertainties and to inform robust decision making and policy discussions.

3 Methods

3.1 Process:

We plan to complete the SFO using an approach that builds on previous assessment efforts, utilizes a public-facing process, and anticipates the need for ongoing updates. Our focus is on maintaining, expanding, and updating reports, projections, and data sets to continue to support the information needs of natural resource decision makers and the interested public in the South.

The SFO will use a question-driven approach and each issue analysis will be organized by a set of specific research questions. Issues, assessment questions, and analysis plans will be circulated for public input. Each issue update will be led by experts who will convene a team of scientists and analysts to conduct the assessment. All reports will be subject to peer and public review before being finalized and reviews will be available to the public. Projection updates will be developed by RPA Assessment specialists located within the Southern Research Station. A team for developing an internet platform for the assessment library will be assigned as the update commences.

3.2 Defining critical issues and research questions:

3.2.1 Defining critical issues

The SFRA (Wear and Greis, 2002a) and the SFFP (Wear and Greis, 2013) afford a wealth of information, much of which is still applicable to today's questions and useful for resource managers. Many of the chapters from those foundational assessments remain relevant today. However, as the SFFP summary findings suggest, the interaction of population growth, climate change, and markets will shape the future forests of the South. Further, interaction among population, climate, and market drivers will have impacts on the types of tools available for forest management (e.g. fire) and the role forests play in water quality and quantity. Current public input through Southern Research Station State-line meetings and SGSF committee discussions have clearly underscored the importance of the following issues: 1) water and forest interactions, 2) timber market conditions and futures, and 3) fire in a changing ecological and social landscape.

The recent scientific literature highlights these issues as well. For example, Martin et al. (2017) found that climate change was a dominant factor in determining water yields but also suggested that increased land use change amplified the impacts of climate change. Prestemon et al. (2016) found wildfire futures were influenced by shifts not only in climate but also in population, income, and land use. Flanagan et al. (2019) suggested that continued controlled burning was key to lower carbon emissions as compared to a wildfire alternative. Wear et al. (2016) and Prestemon et al (2015) found that the global share of US industrial roundwood production peaked at 28% in 1999 but had declined to 17% in 2013. Wear et al. (2016) further suggested that the decline was attributable to a combination of cyclical factors and long-run trends. While the relevance of fire, water, and markets to society cannot be understated, the amount of forest and the conditions of the forests both now and in the future underpin any assessment and futuring of these issues. The assessment and projection of land use change and forest conditions will be completed to provide context for the Outlook's assessment of water and forest interactions, timber market conditions and futures, and fire in a changing ecological and social landscape.

3.2.2 Defining draft research questions

Several information sources were considered for identifying draft research questions for the water, fire, and market issues. These sources included current literature, the findings of the SFFP and SFRA, public meetings conducted for the SFFP and SFRA, Southern Research Station Stateline and Greenline meetings, and SGSF committee meetings. The SFO team examined the summary findings from the SFFP and the SFRA, reviewed all public input resources (Table 1), and further considered the scientific literature to develop draft research questions for each issue. Research questions for the land use change and forest conditions assessment were developed by considering the contextual information needed to address the draft water, fire, and markets issue questions. The draft research questions for the water, fire, and markets issues were presented to the SGSF Water Resources Committee, Fire Committee, and Services, Utilization, and Marketing Committee, respectively, for their input. Following these engagements, the issue research questions were refined to reflect input.

Table 1. Summary of public input sources.

Input	Location	Dates	Citation
Southern Forest Resource Assessment public meetings	5 public sessions across the South	August, 1999	https://www.srs.fs.usda.gov/sustain/meetings/input1/public-inputs1.pdf
Southern Forest Futures Project public meetings	14 public sessions across the South, 3 webinars	January-April 2008	https://www.srs.fs.usda.gov/futures/input/index.html
SRS Stateline meetings[1]	12 meetings across the South	2012-	--
SRS-NFS Region 8 Greenline meetings[2]	3 meetings across the South	2018-	--
SGSF Water Resources Committee	Auburn, AL	January 2020	--
SGSF Fire Committee	Webinar	February 2020	--
SGSF Service, utilization, and marketing committee	Webinar	March 2020	--

[1]SRS Stateline meetings are meetings between the Southern Research Station and State forestry organization professionals from two or three adjacent states.

[2]SRS-NFS Region 8 Greenline meetings are meetings between the Southern Research Station and National Forest managers.

3.3 SFO framework

Shifts in the forest sector are necessarily linked and as such the SFO will link issue analyses to a broader set of drivers. At the broadest level, climate, economics, and population are key drivers that influence not only land use change and shifts in forest conditions but also markets, forest water interactions, and fire (both wildfire and prescribed fire). Likewise, the amount of forest and conditions of those forests influence fire dynamics, water interactions, and the amount of fiber available for products (Figure 1). Models and research questions will be linked to maintain key feedback loops among relevant endpoints. For example, the ability of forests to provide high quality and abundant water depends not only on the amount of forest, but the spatial arrangement of forests in the watershed and the species composition. The amount of forest and the spatial arrangement of forests are linked to both socioeconomic and climate futures, while the species composition of forests is linked to market futures, climate futures, and disturbance futures. Understanding these linkages and including appropriate feedbacks will lead to a better understanding of the issues and potential policy mechanisms needed to shift undesirable trends.

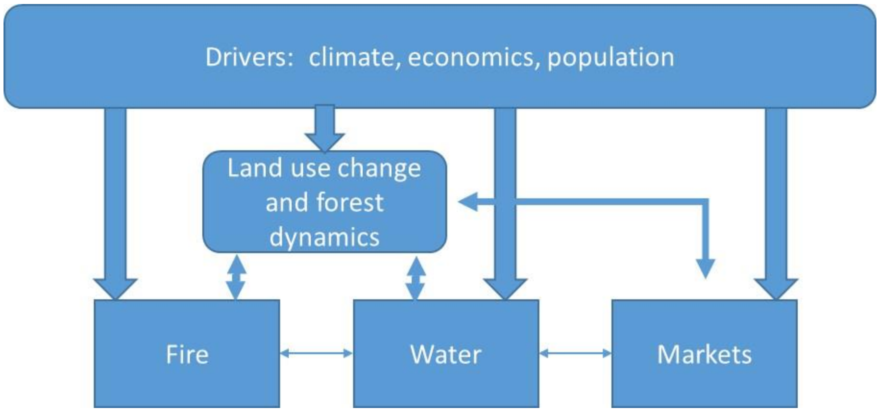

Figure 1. Interactions of drivers and issues in the Southern Forest outlook.

3.4 Integration with 2020 RPA

The Forest and Rangeland Renewable Resources Planning Act of 1974 mandates a national report (RPA Assessment) on the conditions and trends of renewable resources on all forest and rangelands every ten years. The RPA Assessment provides a snapshot of current U.S. forest and rangeland conditions and trends, identifies drivers of change, and projects 50 years into the future (2020-2070 for the 2020 RPA). The 2020 RPA design seeks to anticipate future challenges and support resource management and policy deliberations of interest to multiple audiences in public and private spheres. The focal areas of the RPA are land resources, forest resources, forest products, rangelands, water resources, wildlife/biodiversity, and recreation.

We will leverage the work of the 2020 RPA assessment for the SFO. The RPA assessment system is linked in terms of the overall drivers (climate, population, and income), land use change, forest condition (dynamics), and markets. We will use RPA data, projections, and models when possible. Table 2 highlights key data products and projections available from the RPA assessment team.

Table 2. Data and projections available for the Southern Forest Outlook from the RPA assessment.

Data/Projections	Scale	Period	Citation
Climate	4 km gridded	Historic-2100	Abatzoglou and Brown 2012
Population and Income	County	Historic-2070	Wear and Prestemon 2019a, b
Land use change	County 90 m gridded	Historic-2070 2015-2070	Mihiar and Lewis 2019 Brooks et al. in rev
Forest conditions	FIA plot-level, 90 m gridded	Historic-2070 2015-2070	Coulston et al. in preparation
Forest Products	Subregion	Historic-2070	Guo et al. 2019

Rather than forecasting or predicting conditions from 2020-2070, the emphasis of the SFO will be on understanding the range of plausible outcomes given a set of assumptions around climate, population, and income. This is consistent with the RPA effort. As part of the RPA effort, a set of core scenarios was developed from the IPCC scenarios. The IPCC provides a global context for a range of potential futures. The climate futures are defined in terms of differing representative concentration pathways (RCPs), (IPCC, 2014). The RCPs are defined by radiative forcing (W m^{-2}). In simple terms the radiative forcing is the difference between energy being absorbed by the earth and the energy being reflected and emitted back into space. When the balance is greater than zero, warming occurs. For the 2020 RPA assessment RCP4.5 and RCP8.5 were selected. RCP4.5 has a radiative forcing of 4.5 W m^{-2} at stabilization (after year 2100) with a CO_2-equivalent concentration of ~650 ppm. RCP8.5 has a radiative forcing of more than 8.5 W m^{-2} in 2100 with a CO_2-equivalent concentration of more than 1370 ppm (Moss et al. 2010).

From a socioeconomic perspective, scientists are challenged to align socioeconomic paths that are consistent with RCP paths (van Vuuren et al. 2014). Shared socioeconomic pathways (SSP) were developed after the RCPs and the SSPs offer economic and demographic storylines (O'Neill et al. 2017). The four SSPs (SSP1, SSP2, SSP3, and SSP4) range from a wealthy and increasingly economically equal world that has a focus on climate change mitigation and slowing population growth (SSP1), an economically wealthy world with more focus on adaptation and high U.S. population growth but slower global population growth (SSP5), a less wealthy world with continued inequality and low U.S. population growth and high global population growth (SSP3), and an intermediate case intended to roughly replicate current rates of economic and population change (SSP2). The RPA scenarios are based on combining RCPs and SSPs. Langer et al. (2020) provides a description of the scenarios for the United States (Figure 2) and these scenarios will also be evaluated as part of the SFO.

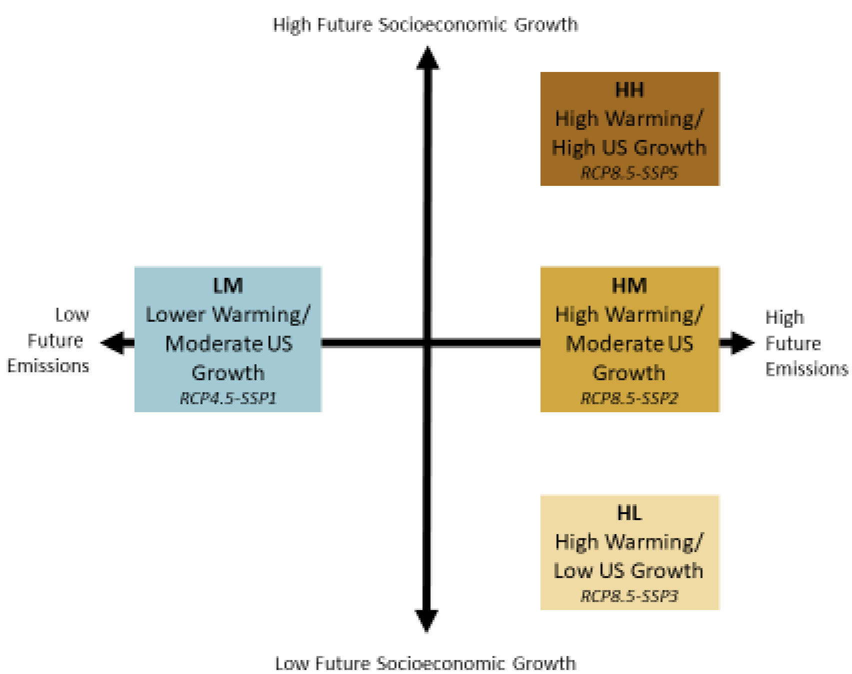

Figure 2. Scenarios develop for the 2020 RPA assessment.

There are four RPA scenarios. The LM scenario (low warming / moderate U.S. growth) is based on the combination of RCP4.5 and SSP1 and describes a future with medium growth (3.0 X current) in U.S. real gross domestic product (GDP), medium population growth (1.5 X current), and lower global emissions. The HL scenario suggests low U.S. population growth (1.0 X current) and low growth in U.S. real GDP (1.9 X) but with high emissions (Table 3). The HH scenario describes a future with high warming and high

U.S. growth. U.S. real GDP increases 4.7 X current levels and population growth increases 1.9 X under the HH scenario. These growth increases are coupled with high global emissions. Between the HL and HH scenarios is the HM scenario which has high global emissions and, consequently, high warming. The U.S. growth is moderate; 2.8 X increase in U.S. real GDP and 1.4 X increase in U.S. population growth. More information about these scenarios is available in Langner et al. (2020).

Table 3. Characteristics of the four 2020 RPA Assessment scenarios.[a] (Source: Langner et al. 2020).

Characteristic	Scenario LM	Scenario HL	Scenario HM	Scenario HH
Global warming and U.S. socioeconomic growth	Lower warming and moderate U.S. growth	High warming and low U.S. growth	High warming and moderate U.S. growth	High warming and high U.S. growth
Global real GDP[b] growth, 2020–2070	Medium (4.9X)	Low (3.2X)	Medium (4.6X)	High (6.9X)
Global population growth, 2020–2070	Low[c] (1.2X)	High (1.6X)	Medium (1.4X)	Low (1.2X)
U.S. real GDP growth, 2020–2070	Medium (3.0X)	Low (1.9X)	Medium (2.8X)	High (4.7X)
U.S. population growth, 2020–2070	Medium (1.5X)	Low (1.0X)	Medium (1.4X)	High (1.9X)
Global emissions	Lower	High	High	High
Global scenario links	RCP4.5-SSP1	RCP8.5-SSP3	RCP8.5-SSP2	RCP8.5-SSP5

[a] Numbers in parentheses are the factors of change in the projection period. For examples, U.S. real gross domestic product increases by a factor of 3.0 between 2020 and 2070 in Scenario LM.

[b] GDP = gross domestic product (based on estimates by the International Institute of Applied Systems Analysis 2019).
[c] Note: Low population involves initial increase with declines in the latter decades of the projection period.

RCPs are designed to capture the range in radiative forcing (W m^{-2}) found in the scientific literature. Radiative forcing is also used as input into General Circulation Models (GCM) which are used to model future climates. There are numerous competing GCMs and five of those GCMs were selected to pair with each scenario. The five GCMs can generally be classified into least warm, hot, dry, wet, and middle climate futures for the U.S. (Table 4**,** Joyce and Coulson, in Press). In total, there are 20 Scenario by GCM combinations that will be evaluated.

Table 4. General Circulation Model used for each RPA scenario (Source: Langner et al. 2020).

	Least Warm	**Hot**	**Dry**	**Wet**	**Middle**
RCP 4.5	MRI-CGCM3	HadGEM2-ES	IPSL-CM5A-MR	CNRM-CM5	NorESM1-M
RCP 8.5	MRI-CGCM3	HadGEM2-ES	IPSL-CM5A-MR	CNRM-CM5	NorESM1-M
Climate model Institution	Meteorological Research Institute, Japan	Met Office Hadley Centre, United Kingdom	Institut Pierre Simon Laplace, France	National Centre of Meteorological Research, France	Norwegian Climate Center, Norway

3.5 Long-term trajectories and scenarios

The SFO is designed utilizing a projection approach. In this manner, the goal is to understand potential shifts in the goods and services that the forests of the southern U.S. provide given a range of long-run trajectories in terms of climate and socioeconomics as defined by the scenarios. Variability along a single long-term trajectory is expected and the scenarios are expected to cover the range in potential futures. For example, figure 3 shows a hypothetical example of a long-run trajectory with a substantial deviation or event. Two post-event paths are shown: a return to the long-run trajectory and the emergence of a new long-run trajectory. In this example the two scenarios (A and B) do a reasonable job of capturing the range of potential futures.

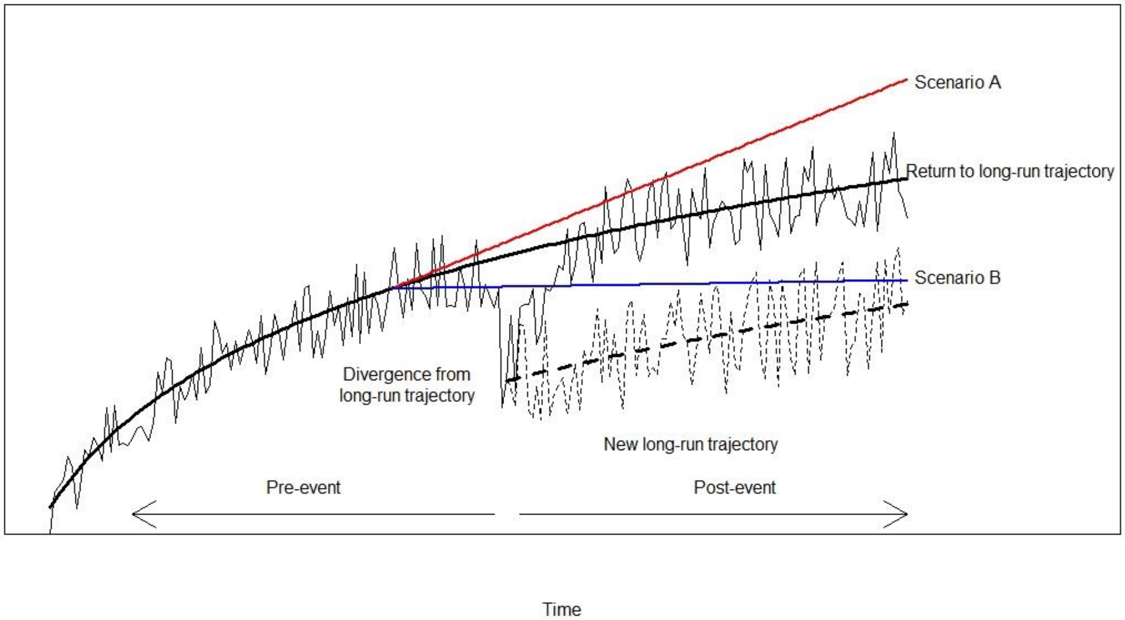

Figure 3. Hypothetical example of a long-run trajectory (thick solid black lines) with a divergence arising from an "event". Two post-event paths are displayed: return to long-run trajectory and the emergence of a new long-run trajectory (dashed line).

At the time of the development of this study plan, the southern U.S. and the world are experiencing a global pandemic. The long-run impacts of the corona virus disease 2019 (COVID-19) are unclear at this point. As more information becomes available regarding the impacts of COVID-19, the principal investigators of this study will carry out sub-analyses designed to determine whether the scenarios, as defined, are appropriate or if a separate scenario is required for completeness.

3.6 Issues

3.6.1 Fire

3.6.1.1 Key findings from SFFP

As an integral part of the southern landscape, fire was included as a chapter in the Southern Forests Future Project (SFFP) that was completed in 2012 (Wear and Greis, 2013). The chapter described potential changes in fire risk across the South associated with a changing climate and examined factors affecting the use of prescribed fire as a management tool in the southern U.S. (Chapter 17; Stanturf and Goodrick, 2013). Key findings from that effort included:

- Climate forecasts indicate that the South's spring and fall wildfire seasons will be extended.
- Prescribed fires, currently conducted on roughly a 3 to 5 year rotation across much of the South, would need to become more frequent if conditions become drier.
- Major wildfire events, such as the 2007 Okefenokee wildfires, 2008 Evans Road Fire in eastern North Carolina, and recent west Texas fire seasons, are also likely to occur more often. Such events currently occur once every 50 years; however, they could become more frequent in a warmer/drier climate.

- Land use change will have the most immediate effects on fuels and wildland fire management by constraining prescribed burning and increasing suppression complexity and cost.
- Air quality issues will likely increase restrictions on prescribed burning over large areas, not just in the wildland-urban interface.
- Potential health and safety concerns, in addition to air quality restrictions, will add to the regulatory constraints on the use of prescribed burning.
- Alternatives to prescribed burning are generally not cost effective and do not provide the ecological benefits of fire to adapted ecosystems; nor do they provide adequate protection for structures and human communities.
- Restrictions on use of prescribed burning to manage fuels will exacerbate potential climate change effects, particularly in the Coastal Plain and on the western Appalachian Mountains, where models predict an increase in wildfire potential.
- Fuels buildups combined with more intense wildfires under a warmer, drier climate could severely degrade fire-dependent communities that often support one or more threatened, endangered, or sensitive species.
- In addition to increasing the severity of wildfire events, the drier conditions and increased variability in precipitation that are associated with climate change could hamper successful forest regeneration and cause shifts in vegetation types over time.

3.6.1.2 How science has progressed from SFFP

The primary tool used to examine the potential impacts of climate change in the Fire chapter of the SFFP was a simplified drought index balancing potential evapotranspiration and rainfall at the monthly time scale (Stanturf and Goodrick, 2013). While this tool was adequate for addressing broad questions such as changes in fire season duration, it lacked the ability to inform discussions on changes in prescribed fire prescription windows. Advances in downscaling methodologies have greatly expanded the level of detail available for climate studies, both in terms of spatial and temporal resolution, and an expanded array of weather parameters. For the SFFP, the weather parameters available were county level estimates of monthly mean temperature and monthly total precipitation. More recent studies have taken advantage of new statistical downscaling methods to examine fire danger using daily 4-km grids of temperature, relative humidity, wind speed, and radiation (Abatzoglou and Brown 2012; Sheehan et al. 2015). Additionally, studies have utilized dynamical downscaling for studies of fire potential that look at both surface weather conditions (Liu et al., 2013) as well as more complex indices that require data at multiple vertical levels in the atmosphere (Bedel et al., 2013).

Liu et al. (2014) built upon the SFFP to further explore climate change impacts on wildland fire and potential mitigation options for land management agencies. Findings highlight the linkage between wildfire activity and societal factors. These factors could potentially lead to a reduction in overall fire activity despite the climate favoring an extended fire season when coupled with reductions in future forest area. Similarly, competing factors could lead to fuel loadings across the region increasing or decreasing depending on the balance between future forest productivity and decomposition rates as both factors are impacted by changes in climate. Such changes will depend upon vegetation type, soils, and the magnitude of temperature and precipitation anomalies from current conditions.

Prescribed burning is presented as a key forest management tool that has been used extensively in the South to lower wildfire risk and it may be among the most useful options for mitigating many climate change impacts. Higher rates of prescribed burning would bring new challenges to fire and land managers as the use of prescribed fire is limited by many factors, including weather conditions, risk of escape, and smoke-related safety and air quality concerns. As with wildfire risk, the ability to conduct prescribed fire is dependent upon availability of suitable weather conditions which will also be shifting in the future (Kupfer et al., 2020).

In 2009, Congress enacted the Federal Land Assistance, Management, and Enhancement Act (FLAME Act, H.R. 5541), mandating the development of a national cohesive wildland fire management strategy that encompasses wildland fire management across all lands in the U.S. As part of this effort the National Science and Analysis Team (NSAT) was established by the Wildland Fire Executive Committee to apply scientific processes to the development and implementation of the National Cohesive Wildland Fire Management Strategy (Cohesive Strategy). Primary tasks assigned to the NSAT included:

1. Assemble credible scientific information, data, and preexisting models that can be used by all teams working on the Cohesive Strategy.
2. Develop a conceptual framework that describes the relative effectiveness of proposed actions and activities on managing risks associated with wildland fire.
3. Construct an analytical system using the products developed in Tasks 1 and 2 to quantitatively analyze regional and national alternatives identified by regional and national strategy committees.

Conceptually, the Cohesive Strategy examines how a collection of management actions and policies collectively influence four major interacting processes: vegetation composition and structure, wildfire extent and intensity, response to wildfire, and community preparedness and resiliency. These processes in turn influence the goods and services received from forests and rangelands, as well as firefighter and public safety. This effort produced a tremendous amount of consistent, standardized data. In addition, it provides a conceptual framework for examining the comparative risk in a consistent manner for all lands in the U.S.

3.6.1.3 Research questions

The research questions for the fire component of the SFO were derived from information gathered from a number of forums such as the SFRA and SFP public comments, Greenline and Stateline Meetings, and Southern Group of State Foresters Fire Committee meetings (Table 1). Questions will be addressed through a combination of syntheses of available literature, modeling, and data summaries/analyses (see methods):

1. ***How are demographic changes influencing wildfire response and prescribed burn implementation and what is the impact of not burning?***

For this question, we will review recent literature exploring demographic changes across the region and how these changes may alter wildfire response and prescribed fire activities. One focus will be the potential impacts of not burning such as tradeoffs in wildfire risk reduction, carbon sequestration and air quality. Recent literature comparing prescribed fire against alternatives fuel treatments such as mechanical treatments will also be reviewed.

2. ***What are the anticipated changes in fire regimes?***

Anticipating changes in fire regimes is a multifaceted problem that will require a combination of literature review and exploration of climate change scenarios through data summary and landscape ecological modeling.

3. ***What are the issues with fire in the wildland urban interface (WUI) and what are the anticipated changes given changes in land use, climate, and forests?***

Information from the Cohesive Strategy work will be integrated with projections of land use and climate change to explore how issues identified through the Cohesive Strategy process may evolve through time. In addition, the Southern Group of State Foresters Wildfire Risk Assessment will be utilized to examine WUI issues at the local scale.

4. ***What are the differences between wildfire and prescribed fire in terms of smoke impacts and carbon consequences?***

We will build upon existing knowledge with new simulations of emissions scenarios that compare the relative contributions of wildfire and prescribed fire smoke to public smoke exposure for a range of prescribed fire management (and wildfire?) scenarios.

5. ***What are the anticipated changes in prescribed fire windows?***

A combination of existing literature and the climate change scenarios will be used to define prescribed fire prescription windows and examine changes in their frequency of occurrence. As desired prescribed fire conditions can vary across ecosystems, fire manager input will be solicited to identify prescription windows for common fire dependent systems.

3.6.1.4 Methods: fire

Synthesis of Current Literature

Synthesizing the current literature is a key component to addressing each of the fire issue area questions. These syntheses will focus on peer reviewed scientific publications, but will also pull from climate change assessment reports, state forestry BMP guidance and experience, as well as other issue analyses in the SFO. Where appropriate, we will refine information down to a sub-regional scale (e.g., state, ecoregion).

Modeling

Questions 2-5 all require a degree of modeling to project future conditions. The modeling efforts will make use of the climate, land use change, and forest condition projections described in Table 2. Crosswalk matrices will be developed between forest conditions and NFDRS fuels layers to support some of the modeling. For question 2, we will utilize a biogeographic description of fire regimes as outlined by Bradstock (2010). While fire regimes are often described in terms of the distribution of fire sizes, fire return intervals, intensity distribution, and fire types, shifting to a biogeographic description allows for understanding the reasons for those fire characteristics and will facilitate projecting future fire regimes. Current and projected forest conditions will be integrated into the fire regime assessment to identify how the range of fire regimes associated with a given forest condition evolve. For question 3, we will use the SGSF Wildfire Risk Assessment (Andreu and Hermansen-Baez, 2008) along with the land use change and forest condition projections to model the influence of changing climate on WUI issues. The multifaceted nature of question 4 will require multiple modeling approaches. For the portion of the question addressing differences in smoke impacts between wildfires and prescribed fires, we will use the BlueSky smoke modeling framework as implemented by Zhou et al. (2019) for examining smoke impacts from the Rough Ridge Fire in the Southern Appalachian Mountains. The carbon sequestration piece of the comparison will follow the work of Flanagan et al. (2019) and utilize the Landscape

Disturbance and Succession II model (LANDIS-II v6.2.1; Scheller et al. 2007), which integrates various ecosystem processes and disturbances that interact at the landscape scale and over longer time periods. Question 5 will build on the work of Kupfer et al. (2020) by incorporating several National Fire Danger Rating System (NFDRS) parameters to provide a more complete prescribed fire window description. Inclusion of the NFDRS calculations will allow us to utilize relationships developed by Freeborn et al. (2016) as an additional means to evaluate shifts in fire regime as well as informing discussion relating to question 1.

Data Summaries and Analyses

Data from modeling efforts and literature syntheses (where possible) will be analyzed and summarized in tables and charts by state and ecoregion to provide critical information at scales relevant to forest managers. When possible, gridded datasets will be developed and archived to facilitate future analyses.

3.6.1.5 Cooperators

Yongqiang Liu, Louise Loudermilk, Joe O'Brien and Marcus Williams, USDA Forest Service Southern Research Station, Center for Forest Disturbance Science.

Steve Flanagan, Kevin Hiers, and Morgan Varner, Tall Timbers Research Station

3.6.2 Markets

3.6.2.1 Key findings from SFFP

The Southern Forests Future Project (SFFP) was completed in 2012 (Wear and Greis, 2013) and included a chapter that focused on forest product markets in the southern U.S. (Chapter 9; Wear et al., 2013). That chapter provides a starting point for the Southern Forest Outlook (SFO) and included the following key findings:

- Although timber production in the South more than doubled from the 1960s to the late 1990s, output levels have declined over the last 10 years, signaling structural changes in timber markets.
- For softwood products, production declines are most clearly related to demand issues. Demand for softwood solid wood products is strongly linked to housing markets, and a sharp decline in construction beginning in 2007 reduced timber demand, a short run adjustment. Demand for pulpwood in paper manufacturing has declined as the production capacity has dropped in the South, a long run adjustment.
- As demand declined, investments in softwood production continued to expand, leading to supply growth for all softwoods, but especially for softwood pulpwood. The net result was a substantial reduction in softwood pulpwood prices.
- In contrast to softwood products, hardwood pulpwood output declined and its price increased in the 2000s, indicating a contraction of supply, especially in the Coastal Plain where paper production is concentrated.
- Several forecasts of timber markets show expanding supplies of softwood timber, especially softwood pulpwood, as new plantations mature and additional plantations accumulate across the South.
- Across all forecasts, softwood pulpwood supply expands through the next 40 years, while softwood sawtimber supply grows over the next decade and then stabilizes.
- Forecasts of hardwood supplies indicate a gradual contraction as urbanization shrinks inventories.
- If timber product demand returns to and stays at the 2006 levels, total timber production is forecasted to expand by about 25 percent over the next 50 years, with little impact on the price of

softwood sawtimber and hardwood pulpwood. Softwood pulpwood prices would decline by about 50 percent.

- If demand growth returns to 1980s and 1990s levels, total timber production could expand by about 40 percent over the next 50 years, with the greatest gains in softwood pulpwood output. Softwood pulpwood prices stabilize at 2006 levels while softwood sawtimber and hardwood pulpwood prices would increase at an average annual rate of slightly less than 1 percent.
- Growth in demand, coupled with gains in the productivity of planted pine forests, would likely expand total timber production by about 70 percent, with the production of softwood pulpwood more than tripling. The price of softwood sawtimber would stabilize, the price of softwood pulpwood would fall at less than 1 percent per year, and the price of hardwood pulpwood would increase by less than 1 percent per year.
- Forecasts indicate that the South's timber supply could expand if moderate rates of future forest investments are added to investments in forests made over the past 20 years. Forecasts for 2055 show that annual production of softwood pulpwood could increase beyond 2006 levels by an additional 2.4 to 3.7 billion cubic feet (36.6 to 57.9 million green tons) without substantial price effects.
- Timber production has the potential to expand substantially in the South, but future markets are likely to be limited by demand levels. Bioenergy is a potential but highly uncertain source of demand. Recovery of housing-related demand for wood products remains a key uncertainty in the short run.
- Without an expansion in timber demand, private forest owners would be expected to eventually experience a strong shift away from forest management as investment returns diminish to the point where continued investments cannot be justified.

3.6.2.2 How science has progressed from SFFP

Since the SFFP was completed, much has changed. Some of the more recent trends in the sector are summarized in Prestemon et al. (2015) and Wear et al. (2016). Some of the salient features include:

- U.S. real economic growth rate has stabilized at less than 2.5% per year, and long-term prospects for economic growth even at that rate are limited, as U.S. population growth approaches zero (U.S. Census Bureau 2020) and global forces push income per capita growth downward during a process of global income convergence (Gordon 2016).
- The solid wood products sector of the United States grew steadily from 2009 through early 2020, with new residential construction rising to a level by the first quarter of 2020 that approximated average rates observed prior to the housing bubble of the mid-2000s.
- With a reduction in the demand for graphics paper in the United States and globally, U.S. production in the paper sector is increasingly dominated by packaging and sanitary papers, although export opportunities for market pulp and packaging paper to China and other countries in Asia with fast growing manufacturing sectors may be trending upward.
- The United States has lost global market share in forest products, mainly due to the overall slower growth of the U.S. economy relative to the global economy and the shift of manufacturing capacity overseas, particularly to Asia. A notable exception resides in the hardwood sector, in spite of relatively slow growth or even shrinkage in hardwood inventories, in which exports of both hardwood logs and hardwood lumber remain robust.
- Recent increases in trade frictions between the United States and its major trading partners has meant generally that the United State is less import-dependent, with gains for U.S. producers and losses for U.S. consumers of solid wood products; net effects of these frictions on the pulp and paper sector are mixed.

- The manufacture and export of wood pellets to the United Kingdom and other European destinations has pushed up demand for small diameter and less economically valuable species in the U.S. South, compensating in some cases for losses in demand by the pulp and paper sector.
- Labor-saving technology changes in the forest products sector have led to a steady decline in employment in the pulp and paper sector, even in the face of modest or weak paper sector growth, while employment in the solid wood products sector has increased somewhat since the 2007-2009 recession.
- The U.S. population growth rate has declined and is trending to replacement levels within the next 15 years, indicating that demand growth in the wood products sector is more likely to be low in the coming decades; weak domestic population growth would lead to low rates of new residential construction (e.g., Prestemon et al. 2018), lower timber prices, lower harvest rates, and rising opportunities for wood product exports.
- As climate change advances, increased carbon and nitrogen fertilization could bolster growth rates, increasing global timber supply and pushing down timber prices, although spatially variable changes in temperature, precipitation, and disturbance frequency hint toward rising price volatility and increasing timber production risks.

In November, 2019, a focused analysis of the SFFP key findings concluded the following:

1. Still Relevant Today
    a. Declining HW inventory and implications for consumers
2. Need to Revisit
    a. Recovery of demand- softwood sawtimber
    b. Increasing softwood inventory into future (relevant)
    c. Still planting?
    d. Price trends under new scenarios
    e. Role of wood energy sector – related to contemporary policies (E.U. and U.K)
3. Recent economic changes associated with the COVID-19 pandemic has likely affected the short-term outlook for the forest products sector in many dimensions.
    a. Construction has likely dropped significantly in recent weeks.
    b. U.S. economic and manufacturing output has likely been negatively affected to a degree reminiscent of the Great Depression.
    c. Initial guesses are that the SFO markets section needs to acknowledge or more directly address the long-run implications of these most recent changes.

3.6.2.3 Research questions

Combining the information generated from Southern Forest Futures public comments, input from Greenline and Stateline Meetings, and discussions with the Southern Group of State Forester's Sustainability, Utilization and Marketing Committee, we have identified the following questions meriting new attention for the Southern Forest Outlook:

1. ***How will markets for forest products change under alternative population, climate, and income futures?***
2. ***How do rates of change in and severity of large scale disturbances affect salvage opportunities, and what are the options for managing salvage on public v private forests?***

3. ***How do relative abundance (inventory) of hardwood vs softwood timber products change under alternative futures?***
4. ***How would different trade policies influence markets for all categories of products?***
5. ***How will future demand for wood energy affect forests, prices, and harvest?***
6. ***How might the emergence of new sources of wood fiber demand, such as growth in the use of mass timber in construction or the demand for wood to manufacture textiles, affect forests, prices, and harvests?***
7. ***What is the outlook for forest sector jobs under alternative futures?***
8. ***What are the long-term implications for the southern forest sector, given COVID-19 and the economic recession?***

3.6.2.4 Methods: markets

The foundation of the SFO Markets section will be built upon a brief review of recent economic conditions in the U.S. and the South (e.g., Wear et al. 2016, Brandeis and Hodges 2015), including recent trends in the timber and forest products sector, and on projections of southern timber and product market conditions emerging from the 2020 RPA assessment.

RPA Models to Project to 2070

The 2020 RPA projects the future of the sector using scenarios that capture the plausible range of future economic and biophysical conditions projected to 2070 (Langner et al. 2020); see Table 3. Projections of global, U.S., and southern markets in the 2020 RPA are carried out with a combined set of projection models of land use by county, forest conditions, and timber harvesting at fine spatial scales, and timber product and secondary forest product markets for RPA regions (for the South, the South-central and Southeast regions), the nation, and globally by country or major overseas region. Additionally, for the United States only, projections of residential construction are made and reported. The global partial equilibrium model of the forest sector, called FOROM (Guo et al. 2019), projects timber inventories, roundwood production, primary product production, and consumption of major categories of forest products (hardwood lumber, softwood lumber, hardwood plywood, softwood plywood, oriented strand board, several categories of pulp, and several categories of paper), prices of those products, and trade in those products by country, outside of the United States, and then by RPA region within the United States.

Changes in forest productivity influence prices. Section 3.4 describes the scenarios in terms of RCP, SSP, and GCMs. RCPs have an associated atmospheric CO_2 concentration level and the GCMs describe climatic changes in temperature, precipitation, and other climate variables. The combination of increased CO_2 and changes in key climate variables leads to forest productivity changes in terms of forest carbon or net primary productivity. These productivity changes occur across countries and have been examined using a global version of a dynamic global vegetation model called MC2 (Kim et al. 2017). The effects of climate change, by RCP on forest productivity for the U.S. generally and for the South, in particular, emerge from the forest dynamics model (discussed in section 3.7.4) using a different projection approach from Kim et al. (2017). FOROM will use forest productivity shifts as defined by MC2 for all countries in the world except the U.S. where the RPA model results will be used.

Downscaling Methods

The 2020 RPA Assessment projections, 2015 to 2070, on land use, timber harvests, and forest variables can be reported at scales from county to state level, from the beginning of the projection to the end

(2070). Projections of forest products sector variables are at spatial scales of multiple states (South-central and Southeast), so downscaling to the state would require development of a downscaling procedure. One possible downscaling procedure would be to allocate projected consumption and production based on historical and projected gross state product (GSP) shares. These GSP shares can be obtained from county-level projections of income available from Wear and Prestemon (2019a, 2019b). A similar downscaling approach for housing to finer spatial scales will be evaluated, including to the South as one U.S. Census region or to the level of individual states. Employment projections could be based on existing Census reporting by state and county.

Prices of timber can similarly be downscaled, although additional challenges exist. We will explore alternative approaches, possibly including prices from private sources (e.g., Timber Mart-South) as a basis, for making price projections for timber and forest products at the state level, although it is not certain that such price projections at the state level will be available. At a minimum, projections of prices will be at the national scale, with the possibility of projecting at the RPA region scale.

Data Sources

Background descriptions of recent history and current status of Southern, U.S., and global forest products markets will be extracted from Wear et al. (2016), the draft Resources Planning Act 2020 Assessment Status and Trends Report (draft), and the latest data from the U.S. Department of Commerce on housing starts (Census Bureau), employment (Bureau of Labor Statistics), domestic production (Bureau of Economic Analysis), population (Census Bureau), timber product outputs by state (USDA Forest Service Forest Inventory and Analysis), international trade quantities and values by product category (U.S. International Trade Commission), southern U.S. timber prices (Timber Mart-South), and southern forest product prices (Random Lengths).

3.6.2.5 Contacts/authors/cooperators

Dr. Craig M.T. Johnston, Bank of Canada – FOROM

Dr. Jinggang Guo, ORISE – FOROM

Dr. John Kim, Pacific Northwest Research Station – MC2

Dr. Prakash Nepal, Forest Products Laboratory

Dr. Consuelo Brandeis, Southern Research Station

3.6.3 Water

3.6.3.1 Key findings from SFFP

The Southern Forests Future Project Wear and Greis, 2013) included a chapter that focused on forests and water in the southern U.S. (Chapter 13; Lockaby et al., 2013). That chapter provides a starting point for reexamining and updating critical forest and water issues and included the following key findings:

- Forest conversion to agriculture or urban use consistently increases discharge, peak flow, and velocity of streams. Sub-regional differences in hydrologic responses to urbanization are substantial.
- Sediment, harmful chemicals, pathogens, and other substances often become more concentrated after forest conversion. If the conversion is to an urban use, the resulting additional increases in discharge and concentrations will produce even higher loads.

- Although physiographic characteristics such as slope and soil texture play key roles in hydrologic and sediment responses to land use conversion, land use (rather than natural geographic processes) is the primary driver of water chemistry responses.
- Conversion of forest land to urban uses may decrease the supply of water available for human consumption and increase potential threats to human health.
- Increases in urbanization by 2060 in the Appalachians, Piedmont, and Coastal Plain would increase imperviousness and would further reduce hydrologic stability and water quality in the headwaters of several major river basins and in small watersheds along the Atlantic Ocean and Gulf of Mexico.
- On average, water-supply model projections for the South indicate that by 2050 the combination of population growth and land-use change will increase water stress by 10 percent.
- Water stress will likely increase significantly by 2050 under all climate change projections, largely because higher temperatures would result in more water loss by evapotranspiration but also because precipitation would decrease in some areas.
- Approximately 5,000 miles of southern coastline are highly vulnerable to sea-level rise.

3.6.3.2 How science has progressed from SFFP

As summarized above, previous syntheses of forest and water interactions for the southern U.S. (e.g., Southern Forest Future Project – Lockaby et al. (2013); Jackson et al. (2004)) provide a solid understanding of the critical role that forests play in regulating water resources. Further, it is increasingly recognized that forest management will be instrumental in keeping forested watersheds healthy and resilient to future stressors in order to provide water-related ecosystem services. Decades of watershed research have provided five key lessons for watershed management (Vose et al., 2016):

1. Forests provide the cleanest and most stable flows of surface water and groundwater recharge among all land uses,
2. Flow amount (water yield) and timing can be altered by forest management; flows can increase or decrease depending upon post-disturbance successional patterns,
3. Nutrient levels in forested watersheds are generally low; however, sediment loading can increase when disturbance results in erosion and sediment delivery,
4. Riparian areas and forested wetlands are especially important for regulating flows and protecting water quality, and
5. The implementation of best management practices is critical for ensuring that forests can be managed to avoid or minimize adverse effects on water resources.

While these key lessons continue to be useful tenants for watershed management, our understanding of forest water interactions has increased substantially since the SFFP Water Chapter (Lockaby et al., 2013) and new challenges have emerged. Forest managers are facing increasing threats from a warming climate and associated changes in extreme weather; and rapid urbanization and demographic changes are increasing the demands for water-based ecosystem services that include drinking water and flood protection (Sun and Vose, 2016). In many parts of the South, conditions are changing faster than anticipated. For example, the decade of the 2010s through 2017 have been warmer than any previous decade in the South (USGCRP, 2018). Further, while the 2000s and 2010s were two of the top three decades since 1900 in terms of the number of days with precipitation greater than three inches (USGCRP, 2018), the duration of consecutive days without precipitation is also increasing (Roque-Malo and Kumar, 2017). These changing climatic conditions are contributing to increased variability in streamflow (Rice et al., 2015) and have cascading effects on other stressors. For example, while wildfires have always occurred in the southern U.S., their historically low frequency has made their impacts on water resources a minor concern. However, the potential increase in larger and more severe wildfires in the future due to climate change (Liu et al., 2013; Mitchell et al., 2014) lead to a growing concern for wildfire impacts on water and aquatic resources (Bladon et al., 2014; Hallema et al., 2018; Hohner et al., 2019; Vose, 2019). Similarly, changes in forest structure and species composition brought about by management, climate change, altered fire regimes, and other disturbances can have a direct impact on watershed water yield (Brantley et al., 2014; Caldwell et al., 2016; Elliott et al., 2017). Future climate and land use change will further increase streamflow variability in the South (Martin et al., 2017; Suttles et al., 2018), potentially leading to more frequent water supply stress (Duan et al., 2019) and flooding events (USGCRP, 2018); and increasing risks to vulnerable human communities (Emrich & Cutter, 2011; Saia et al., 2020) and aquatic ecosystems (Hain et al., 2018).

To meet these unprecedented challenges, land managers will require the best available science to inform innovative approaches for sustainable watershed management in the 21st century. Indeed, based on many past successes, there is an expectation by land managers and the public that we have sufficient knowledge and tools to keep watersheds functioning and capable of providing and sustaining ecosystem services into the future (Vose et al., 2016). This expectation presents a challenge for both researchers and natural resource managers to constantly integrate new science findings into planning and management actions. Recent research, observations, and improved tools provide the foundation for managing watersheds in a rapidly changing environment. For example, the expansion of eddy covariance and sapflow networks measuring evapotranspiration across a broad range of climate and vegetation types (e.g., FLUXNET AMERIFLUX). Regional-scale drought experiments (e.g., PINEMAP) have demonstrated potential implications of more frequent and prolonged droughts on water budgets of southern pine forests (Ward et al., 2015). Improvements in regional scale hydrologic models (Duan et al., 2017; 2019), ever-increasing computing capability, more detailed climate projections, and new techniques to project changes in forest condition and composition (Martin et al., 2017) will increase confidence in updated projections of the effects of climate and land use change on water resources and related ecosystem services that include sustaining drinking water supplies and reducing flood risk. As such, the Water Chapter of the Southern Forest Outlook will provide the most recent and relevant science to inform management of southern watersheds in the 21st century.

3.6.3.3 Research questions

Research questions were formulated using a combination of information generated from SFRA and SFFP public comments, input from Greenline and Stateline Meetings, and discussions with the SGSF Water Resources Committee (Table 1). We will answer the following questions using syntheses of the available literature, modeling, and data summaries/analyses (see methods):

1. ***How has our understanding of forest-water interactions changed since the SFFP?***

For this question, we will review advances in data and available tools to understand forest water interactions in southern forest ecosystems.

2. ***How will changes in climate, land uses, and forest conditions impact water resources in the future?***

Here we will use updated climate, forest conditions, and land use projections in hydrologic models to project changes in the magnitude and quality of streamflow and groundwater recharge across the South. We will focus on understanding responses at a range of spatial and temporal scales to examine the implications of both wet and dry extreme events.

3. ***What are the likely implications of these changes on water supply, flood protection, and other ecosystem services?***

Using the projections noted above, we will assess the implications of projected hydrologic changes for humans and aquatic ecosystems such as the relation between water supply and demand, municipal water treatment, flooding and associated impacts on water infrastructure, riparian forests, and at-risk populations, and aquatic biological integrity. We will summarize the state-of-the-knowledge on quantifying the financial benefits of forests for providing clean and abundant drinking water and the interactions among land use, climate change, social vulnerability, flooding, and risks to human well-being.

4. ***How might these projected changes in climate and water resources interact with other large disturbances such as fire, sea level rise, insect and diseases, and hurricanes?***

Changes in hydrologic conditions will likely have complex feedbacks and interactions with other stressors and disturbances. Here we will assess the interactions and examine their implications.

5. ***What management actions are available (now and in the future) to minimize impacts and increase resiliency anticipating climate change and population rise?***

Here, we will summarize the state-of-the-knowledge on forest management actions such as thinning, forest restoration, species selection, urban forestry, and water quality BMP's that could be used to minimize impacts and increase resiliency.

3.6.3.4 Methods: water

Synthesis of Current Literature

We will synthesize the current literature in responding to questions 1, 3, 4, and 5 above. These syntheses will be derived from peer reviewed scientific publications, climate change assessment reports, State forestry BMP guidance and experience, and other chapters in the SFO. We will distill the information gathered to a sub-regional scale (e.g. state, ecoregion) where possible.

Modeling

We will develop and run hydrological models at a range of temporal and spatial scales that are informed by the 2020 Resources Planning Act (RPA) projections of climate, land use, and forest conditions (Table 2) to respond to question 2 above, using demonstrated and peer reviewed modeling applications such as WaSSI (Caldwell et al., 2012; Sun et al., 2011) and SWAT (Arnold et al., 2012). Key outputs of this modeling effort will include projections of:

- Trends in annual and monthly water yield/water supply/streamflow across the South as influenced by climate, forest, and land use change
- Changes in sub-monthly (e.g., weekly or daily) wet/dry streamflow extremes in important and vulnerable case study watersheds distributed across the region
- Changes in water quality in case study watersheds

Data Summaries and Analyses

Data from modeling efforts and literature syntheses (where possible) will be analyzed and summarized in tables and charts by state, ecoregion, and watershed to provide critical information at scales relevant to forest and water resource managers.

3.6.3.5 Contacts/authors/cooperators

Dr. Ge Sun, USDA Forest Service, Southern Research Station, Eastern Forest Environmental Threat Assessment Center

Dr. Georgianne Moore, Texas A&M Forest Service, Department of Ecosystem Science and Management

Dr. Tom Holmes, Forest Service, Southern Research Station, Forest Economics and Policy

Dr. Chris Mihiar, Forest Service, Southern Research Station, Forest Economics and Policy

3.7 Setting the context: land use change and forest conditions

3.7.1 Key findings from SFFP

The Southern Forests Future Project (SFFP) concluded its land use (Wear, 2013) and forest conditions (Huggett et al. 2013) chapters with the following Key Findings:

- Between 30 million and 43 million acres of land in the South are forecasted to be developed for urban uses by 2060 from a base of 30 million acres in 1997. These forecasts are based on a continuation of historical development intensities.
- From 1997 to 2060, the South is forecasted to lose between 11 million acres (7 percent) and 23 million acres (13 percent) of forests, nearly all to urban uses. All of the South's five subregions are expected to lose at least some forest acreage under all evaluated futures.
- Strong timber markets can ameliorate losses of southern forest somewhat, but this comes at the expense of cropland uses.
- Among the South's five subregions, the Piedmont is forecasted to lose the greatest proportion of its forest area—21 percent under the highest-loss forecast—by 2060. The Mid-South and Mississippi Alluvial Valley are forecasted to lose the smallest proportion (between 8 and 9 percent).
- At 34 percent, Peninsular Florida is forecast to lose the most forest land of the 21 sections nested within the South's five subregions. All sections within the Piedmont subregion are forecasted to lose at least 19 percent of their forest land.
- The area of cropland in the South is forecasted to decline by as much as 17 million acres from 1997 to 2060 from a base of about 84 million acres in 1997. Cropland futures assume constant real returns to agricultural products.
- Cropland losses would be highest in North Carolina, southern Florida, and central Texas.
- Among the five forest management types, only planted pine is expected to increase in area. In 2010 planted pine comprised 19 percent of southern forests. By 2060, planted pine is forecasted to comprise somewhere between 24 and 36 percent of forest area.
- Although predicted rates of change vary, all forecasts reveal that land use changes and conversion to pine plantations will result in a continuing downward trend in naturally regenerated pine types.
- Changes in forest types are influenced by urbanization and timber markets: hardwood types are most strongly influenced by urbanization; softwood types are most sensitive to future timber market conditions.
- Reversing a 50-year trend of accumulating about 2.5 billion cubic feet per year, forest biomass is forecasted to increase slightly over the next 10 to 20 years and then decline gradually.
- After accounting for harvests, forest growth, land use, and climate change, the total carbon pool represented by the South's forests is forecasted to increase slightly from 2010 to 2020/2030 and then decline.

- Urbanization patterns are the dominant determinates of the size of the future forest carbon pool, although stronger forest product markets can ameliorate carbon losses.
- Because of increases in timber supply from 1990 to 2010, removals of forest biomass (growing stock) are forecasted to increase for all Cornerstones (scenarios), including those that project decreasing prices. This reflects an outward shift in timber supply associated with forest inventories between 1990 and 2010.
- Removals of softwood pulpwood are responsive to futures for forest planting and product prices. Under a high price future, softwood pulpwood output would increase by 56 percent, roughly equal to the expansion observed between 1950 and 2000.
- Although the overall loss of upland hardwood acreage is forecasted to be in the range of 8 to 14 percent, the oak-hickory forest type remains essentially constant while the areas of other forest types decline at higher rates. The yellow-poplar forest type is forecasted to decline the most, with the highest losses forecasted for the Piedmont.
- The age and species structure of softwood forest types are most strongly influenced by forest harvesting and management tied to timber markets. This is not the case for hardwood forests.
- The future structure of hardwood forests is most strongly affected by urbanization-driven land use changes (increased population growth and income).
- Reductions of naturally regenerated pine forests are not equally distributed among age classes. Mid-age and early-age forests decline, but old-age forests remain relatively constant.
- The distribution of upland and lowland hardwoods shifts, with less of these forest management types classified as early age and more classified as older age.

3.7.2 How science has progressed from SFFP

Since the SFFP was completed, science has rapidly progressed in both land use change and forest dynamics science areas. Given the rather broad literature base a few salient points are highlighted.

- Several high profile research efforts have highlighted the need to understand not just the amount of net forest area change but also the gross change (Hansen et al. 2013, Coulston et al. 2015). Understanding gross changes (losses and gains) is critical to quantifying the long term impacts of land use choices. Further, recent research emphasizes the importance of climate change on land use future choices (Mihiar and Lewis 2019). The future arrangement of forests is an important component for understanding the role of forests in providing clean water, how the wildland urban interface may shift, and timber availability.
- Empirical and simulation studies have quantified the potential for tree species migration (e.g. Woodall et al. 2009, Iverson et al. 2019), yet shifts in forest community types (forest types) are rarely quantified (Costanza et al. 2018, Wear et al. 2013). Given gross land use change and forest community shifts, the concept of 'the right forests in the right place' has clear relevance to water, fire, and markets.
- Forest plantations remain an important component of the forestry sector in the South and globally. The South has seen a steady increase in plantation area (Chen et al. 2017) and Wade et al. (2019) suggest there is potential expansion given incentive for improved productivity. Yet, climate change and disturbances may influence planting rates (Payn et al. 2015).
- Forest removals for products have increased since 2009 (Wear et al. 2016, Prestemon et al. 2015) however, future removal volumes and forest planting rates depend on both the southern forest

products market and the global market. Understanding market demands for timber is crucial to understanding forest removal volumes and planting rates.

- Forest volume, biomass, and carbon futures are linked. While forest aging, and hence slower growth rates, are expected, it is anticipated that the forests of the U.S. South will continue to be a carbon offset (Wear and Coulston 2015). Further, atmospheric enrichment may increase carbon sequestration in forests. There is a need to understand the role of land use changes, forest community shifts, atmospheric enrichment, and disturbance effects on forest volume, biomass, and carbon simultaneously to offer a more complete perspective on potential futures.

3.7.3 Research questions

The primary scope of the assessment of land use change and forest conditions is to provide context for issue analyses (Figure 1). The specific land use and forest conditions questions identified are designed to provide a consistent framework and data under which the SFO summary can be constructed (Figure 4).

1. How have forest conditions and the amount of forest changed since SFFP?

For this question we will analyze the most recent Forest Inventory and Analysis and Natural Resources Inventory estimates to highlight current status and recent trends in forest conditions and land use change.

2. How will the amount of forest and its distribution among other land uses change under alternative climate, population, and income futures?

Projections of gross land use change are partially driven by climate, population, and income futures. Using the 90 m gridded land use projections (Table 2) we will quantify the amount of forest, the spatial arrangement of forests, the distribution of forest among other land uses, and how the amounts, arrangements and distributions differ across scenarios.

3. How will forest composition and structure change under alternative futures?

We will use projections of forest conditions to quantify and examine potential shifts in forest types (including plantations), age structure, timber volume, and carbon under alternative climate, population, and income futures.

4. What is the role of forest disturbance and management in influencing future composition and structure?

For this question we will examine the range of forest disturbance impacts across scenarios and relate these findings to question 3. Further, we will examine the potential inventory implications of limiting prescribed burning in the RPA Forest Dynamics Model.

5. How are inventory removals for forest products expected to change under alternative market futures?

The RPA Forest Dynamics Model is harmonized with the markets model so that removals from the inventory reflect market demand for roundwood. For this question we will quantify inventory removals for each scenario.

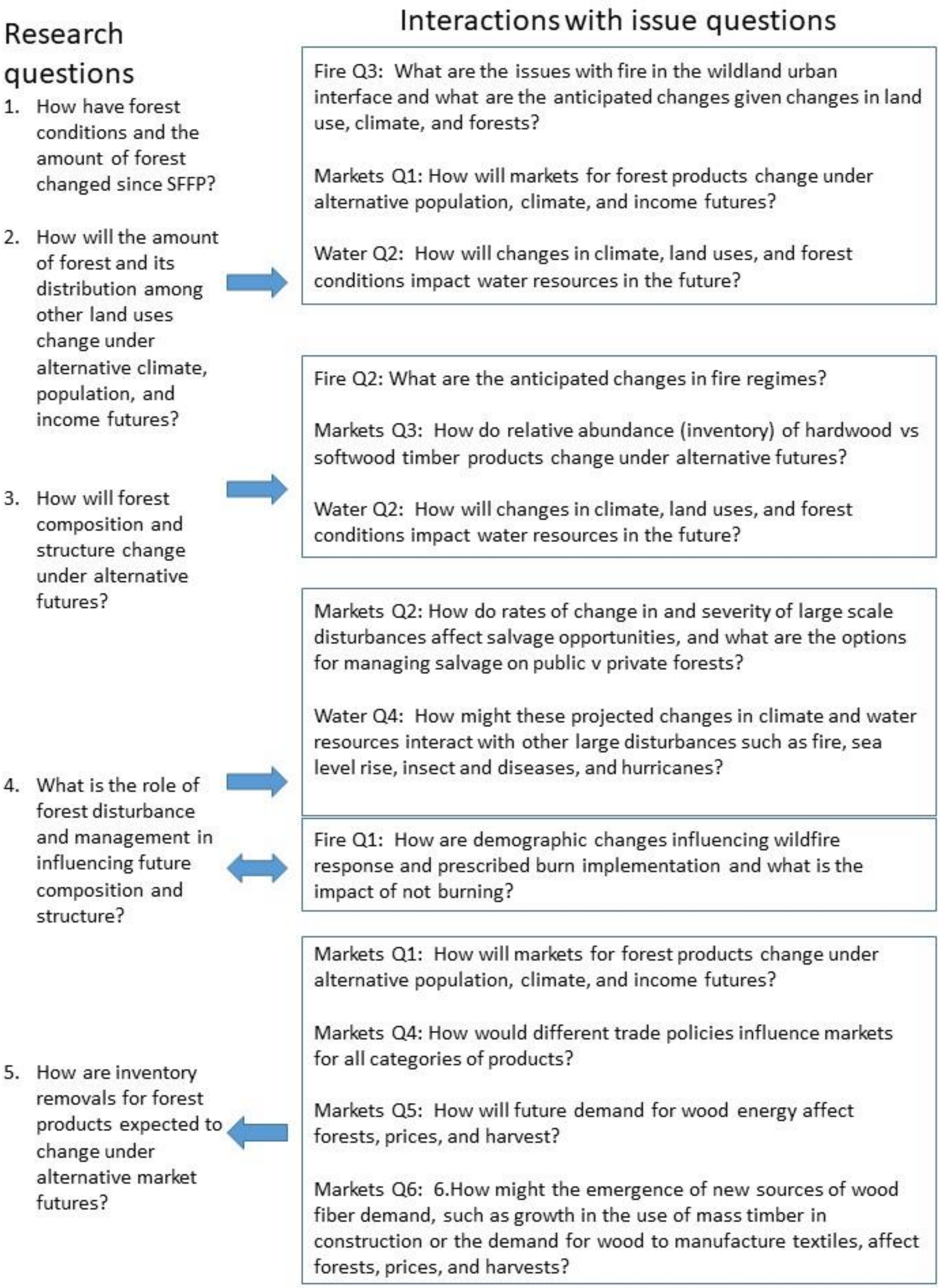

Figure 4. Land use change and forest conditions contextual questions and linkages to issue questions. The linkages are information and/or data flows

3.7.4 Methods: land use change and forest dynamics

The suite of RPA products and projections previously described will form the basis for land use change and forest conditions assessment and conditions (Table 2). The land use change model (Mihiar and Lewis 2019) is an econometric model that incorporates climate change and population and income shifts to project land use change among forest, developed land, pasture, cropland, and other land use classes. The model projects gross and net land use change at a county scale for the United States. Generally, the model is a discrete choice model where predicted climate change influences on land rents drives land use conversion probabilities. For many analyses, however, county-scale information on land use change is too coarse. We will also use the down-scaled (90 m gridded) land-use change projections (Table 2, Brooks et al., in review). These down-scaled projections use a stochastic seeding approach where observed patterns of gross land use change among land uses are used to inform future land use transitions. The total amount of gross land use change in the down-scaled product matches the gross land use change at the county-level from the econometric model. The down-scaled land use projections are stochastics and multiple realization (20) are performed for each scenario and time step.

The Forest Inventory and Analysis (FIA) inventory defines the current forest conditions in the southern U.S. Projections of the inventory will rely on the RPA Forest Dynamics Model which is an imputation model that is informed by several state transition models and an atmospheric enrich model (Coulston et al., in prep). The overall modeling approach is an extension of the approaches developed by Van Deusen and Roesch (2013) and Wear et al. (2013). The role of the Forest Dynamics Model is to provide projections of detailed forest conditions for all forested plots in the U.S. Forest Inventory. Stochastic plot state transition models are used to address forest disturbance, forest harvesting/management, climate changes, and forest aging. Plot records are projected using multiple imputation approaches based on the time series to annual FIA data. The multiple imputation approach leads to 50 realized inventories per time step per scenario. Land use change from the RPA land use change model is integrated so that changes in forest extent are represented in the projection. Further, the harvest choice which defines the amount of harvest is integrated with FOROM through a consistent price and supply path.

3.7.5 Cooperators

Dr. Jen Costanza, Southern Research Station

Dr. Evan Brooks, Virginia Tech

Jill Derwin, Oak Ridge Institute for Science and Education

David Walker, Virginia Tech

3.8 Synthesis

The research and findings from the Water, Fire, Markets, Land use, and Forest Conditions components of the SFO assessment will form the basis for a synthesis document that will summarize the critical management and relevant policy components of each issue and place the overall results in a landscape context.

4 Delivery methods

The SFO will utilize several different delivery methods. Issue reports will be published as electronic General Technical Reports as they are completed. The SFO summary/synthesis document will be published in both hardcopy and electronic form. Databases and projections will be published through the U.S. Forest Service Research Data Archive. A web-based delivery mechanism will also be used for online visualization and examination of projections and research results. Story maps and other science delivery methods will also be used to communicate results.

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